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ELECTROSTATIC ACTUATOR

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ELECTROSTATIC ACTUATOR

[Seiden-shiki akuchueeta]

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Claims

1. An electrostatic actuator characterized in that it is equipped with a fixed member having a comb-like fixed electrode, a movable member having first and second comb-like movable electrodes which engage the comb-tooth of the aforementioned fixed electrode while insulated from each other by an insulator, and a guide member for guiding said movable member only in one direction, wherein a voltage is applied via said guide member to one of the aforementioned

movable electrodes and between the fixed electrode and the remaining movable electrode in order to move the aforementioned movable member in one direction.

2. The electrostatic actuator described under Claim 1 characterized in that one of the aforementioned first and second movable electrodes is made of a dielectric.

3. The electrostatic actuator described under Claim 1 or 2 characterized in that at least 2 movable members are layered onto the aforementioned fixed member in order to improve the driving force.

4. The electrostatic actuator described under one of Claims 1 through 3 characterized in that an elastic holding spring is used for the aforementioned guide member.

5. The electrostatic actuator described under one of Claims 1 through 4 characterized in that the aforementioned guide member comprises the comb-teeth of the fixed electrode and a guide rail.

6. An electrostatic actuator characterized in that it is equipped with a cylindrical fixed electrode, first and second movable electrodes provided inside the aforementioned fixed electrode while insulated from each other by an insulator, and a guide member for guiding said first and second movable electrodes only in one direction, wherein a voltage is applied between one of the aforementioned movable electrodes and the fixed electrode via said guide member in order to move the aforementioned movable members in one direction.

7. The electrostatic actuator described under Claim 6 characterized in that the aforementioned insulator and one of the movable electrodes are made of a dielectric.

8. An electrostatic actuator characterized in that it is equipped with a stator having a comb-like fixed electrode, a rotor having first through fourth movable electrodes which engage said [stator] while insulated from each other by an insulator, a first rotary electrode and a second rotary electrode formed on either side of the shaft part of said rotor and which are connected to

the aforementioned first and third movable electrodes, and second and fourth movable electrodes, respectively, and first and second brushes for fixing the aforementioned rotor by pressure to the stator via the first and the second rotary electrodes, wherein a voltage is applied between the aforementioned first brush and the stator in order to rotate the aforementioned rotor.

9. The electrostatic actuator described under Claim 8 characterized in that a dielectric is used for the aforementioned insulator and the first and third movable electrodes, or the insulator and the second and fourth movable electrodes.

10. An electrostatic actuator characterized in that it is equipped with a rotor having first and second movable electrodes created by cutting a disk while said electrodes are insulated from each other by an insulator and a pair of stators which sandwich to support said rotor while allowing it to rotate, wherein a voltage is applied to the second electrode from the shaft holding part of the stators in order to rotate the aforementioned rotor.

11. The electrostatic actuator described under Claim 10 characterized in that a dielectric is used for the aforementioned insulator and one of the movable electrodes.

<u>Detailed explanation of the invention</u>

[0001]

Industrial application field

The present invention pertains to an electrostatic actuator which utilizes an unbalance in field strength to obtain a driving force.

[0002]

Prior art

A conventional example of said type is shown in Figure 13. Here, comb-like fixed electrode F and movable electrode M engage at an appropriate distance, and a voltage is applied to them, whereby their position is displaced in the direction of the length to obtain an electrostatic driving force proportional to the number of comb-teeth. The position is displaced in the direction indicated by arrow R1 when a voltage is applied in the manner indicated by ①, and the position is displaced in the direction indicated by arrow R2 when a voltage is applied in the manner indicated by ②. Furthermore, H indicates a holding part (fixed part). In this case, acting electrostatic driving force F can be expressed as

$$F = \varepsilon \cdot n \cdot t \cdot V^2/2d,$$

wherein ε represents the relative dielectric constant, d represents the size of the gap, n represents the number of comb-teeth, t represents the thickness of a tooth, and V represents the voltage applied. Another conventional example is shown in Figure 14. In this case, fixed electrode F and movable electrode M are provided to face each other, and a voltage is applied to them in order to obtain an electrostatic force F in a direction so as to reduce the gap in the manner indicated by the arrow. In this case, electrostatic driving force F can be expressed as

$$F = \varepsilon \cdot S \cdot V^2/2d^2,$$

wherein ε represents the relative dielectric constant, d represents the size of the gap, S represents the facing area, and V represents the voltage applied.

[0003]

Problems to be solved by the invention

Because the latter is inversely proportional to the square of gap size d, it has a problem that no driving force can be obtained when the gap is increased so as to increase the amount of the positional displacement. On the other hand, although the amount of positional displacement can be increased more with the former than the latter, the number of comb-teeth, the gap size, and the tooth thickness which can be fabricated are subject to limitations, resulting in a problem that a large driving force cannot be obtained. Therefore, the purpose of the present invention is to generate a large driving force and displacement.

[0004]

Means to solve the problems

In order to solve such problems, the first invention is characterized in that it is equipped with a fixed member having a comb-like fixed electrode, a movable member having first and second comb-like movable electrodes which engage the comb-tooth of the aforementioned fixed electrode while insulated from each other by an insulator, and a guide member for guiding said movable member only in one direction, whereby a voltage is applied via said guide member to one of the aforementioned movable electrodes and between the fixed electrode and the remaining movable electrode in order to move the aforementioned movable member in one direction. The second invention is characterized in that in the first invention, one of the aforementioned first and second movable electrodes is made of a dielectric. In addition, the third invention is characterized in that in the first or the second invention, at least 2 movable members are layered onto the aforementioned fixed member in order to improve the driving force. Furthermore, the fourth invention is characterized in that in one of the first through the third inventions, an elastic holding

spring is used for the aforementioned guide member. In addition, the fifth invention is characterized in that in one of the first through the fourth inventions, the aforementioned guide member comprises the comb-teeth of the fixed electrode and a guide rail.

[0005]

The sixth invention is characterized in that it is equipped with a cylindrical fixed electrode, first and second movable electrodes provided inside the aforementioned fixed electrode while insulated from each other by an insulator, and a guide member for guiding said first and second movable electrodes only in one direction, whereby a voltage is applied between one of the aforementioned movable electrodes and the fixed electrode via said guide member in order to move the aforementioned movable members in one direction. The seventh invention is characterized in that in the sixth invention, the aforementioned insulator and one of the movable electrodes are made of a dielectric. In addition, the eighth invention is characterized in that it is equipped with a stator having a comb-like fixed electrode, a rotor having first through fourth movable electrodes which engage said [stator] while insulated from each other by an insulator, a first rotary electrode and a second rotary electrode formed on either side of the shaft part of said rotor which are connected to the aforementioned first and third movable electrodes, and the second and fourth movable electrodes, respectively, and first and second brushes for fixing the aforementioned rotor by pressure to the stator via the first and the second rotary electrodes, whereby a voltage is applied between the aforementioned first brush and the stator in order to rotate the aforementioned rotor.

[0006]

The ninth invention is characterized in that in the eighth invention, a dielectric is used for the aforementioned insulator and the first and third movable electrodes, or the insulator and the second and fourth movable electrodes. In addition, the tenth invention is characterized in that it is equipped with a rotor having first and second movable electrodes created by cutting a disk while insulated from each other by an insulator and a pair of stators which sandwich to support said rotor while allowing it to rotate, whereby a voltage is applied to the second electrode from the shaft holding part of the stators in order to rotate the aforementioned rotor. Furthermore, the eleventh invention is characterized in that in the tenth invention, a dielectric is used for the aforementioned insulator and one of the movable electrodes.

[0007]

Operation of the invention

The pair of movable electrodes insulated from the comb-like fixed electrode are arranged so as to engage with each other, and a voltage is applied to one of the movable electrodes and between the fixed electrode and the remaining movable electrode, whereby a large driving force can be generated in order to increase the displacement. In addition, in place of the pair of movable electrodes, the configuration may use an electrode and a dielectric.

[0008]

Application examples

Figure 1 is an oblique view of an application example of the present invention. In said figure, 1 is a fixed member formed with comb-like fixed electrode 11, 2 is a movable member formed with first and second movable electrodes 21A and 21B (see Figure 2) via an insulating

layer, and 3A and 3B are guide members. That is, the configuration involves a pair of movable electrodes 2 which are insulated from comb-like fixed electrode 1 and arranged in such a manner that they engage with each other. Furthermore, although a spring is assumed for the guide member here, anything can be used as long as it has the same functionality. Figure 2 is a diagram for explaining the principles of the present invention. It shows a portion of cross section A in Figure 1, wherein 2 fixed electrodes 11A and 11B and a pair of movable electrodes 21A and 21B are arranged in the manner illustrated. For example, movable electrode 21A and fixed electrodes 11A and 11B are connected to the negative pole of power supply V, and movable electrode 21B is connected to the positive pole of power supply V so as to vary the intensities of the fields acted upon movable electrodes 21A and 21B in order to obtain electrostatic driving force F. Furthermore, at this time, electrostatic driving force F is

$$F = \varepsilon \cdot n \cdot L \cdot V^2/2d.$$

Here, L represents the length of the comb-like electrode. At this time, because a force is generated at the movable electrode as long as the movable electrode stays within the fixed electrodes, the displacement can be increased by increasing the height of the fixed electrodes. In addition, because the force generated is proportional to the length L of the comb-like electrode, electrostatic driving force F can be increased more than with a conventional design. In addition, in the case shown in Figure 13, while force is generated constantly by half of the total number of comb-teeth, the force is generated constantly by the total number of teeth-teeth in the present application example, so that a greater force can be attained.

[0009]

Therefore, in the configuration in Figure 1, when guide member 3B and fixed member 1 are connected in the manner indicated by ①, and voltage V indicated by the solid line is applied

between guide member 3A and fixed member 1, movable member 2 moves in the direction (upward) indicated by the solid-line arrow according to the aforementioned principle. In addition, when guide member 3A and fixed member 1 are connected in the manner indicated by ②, and voltage V indicated by the dotted line is applied between guide member 3B and fixed member 1, movable member 2 moves in the direction (downward) indicated by the dotted-line arrow according to the same principle. At this time, guide member 3A and movable member 21A are connected with each other, and guide member 3B and movable member 21B are connected with each other for the voltages to be applied to movable electrodes 21A and 21B via guide members 3A and 3B. The outline of a method for fabrication is shown in Figure 3. First, in (A), an insulating film and Si are layered on a silicon (Si) substrate. Next, after the contour of the movable member is formed by means of etching in (B), etching is applied from the back side in order to create the movable member in (C).

[0010]

Although 1 unit of a movable member was involved in Figure 1, 2 or more units may be layered. Figure 4 is a slanted view showing an application example of such kind, wherein 3 units are layers. As described above, when 3 movable members are layered while keeping an appropriate gap between them, the aforementioned electrostatic force acts upon each movable member, so that a driving force 3 times as intense as the one in Figure 1 can be obtained. Accordingly, a driving force N intensified by times can be obtained when N units are layered. The outline of a method for fabrication is shown in Figure 5. (A) and (B) are identical to those in Figure 3. In (C), an insulating film and a sacrificial layer are formed. Then, after a second substrate (Si, insulating film, Si) is layered on top as shown in (D), the contour of a second movable part is formed in (E). Furthermore, a sacrificial layer, an insulating layer, and a third

substrate are layered in (F), and the contour of a third movable part is formed in (G). Finally, etching is applied from the back side in (H) in order to form the first movable part, and the sacrificial layer is removed to complete it.

[0011]

Although a pair of movable electrodes are provided via an insulating layer in Figure 2, either the insulating layer or the movable electrodes may be replaced by a dielectric. Figure 6 is a diagram for explaining such principle. Here, only movable electrode 21A is provided, pasted with dielectric (dielectric constant of εA) 21D, and placed to face fixed electrodes 11A and 11B. Then, it is placed in liquid flon or alcohol having relative dielectric constant εB higher than that of dielectric 21D, and a voltage is applied in the manner illustrated. When so done, similar driving force F as that in Figure 2 can be obtained. Here, assuming that $\varepsilon A < \varepsilon B$, field intensity of the upper plane is E1, and field intensity of the lower plane is E2, driving force F is expressed as

$$F = \varepsilon B\,(E1^2 - E2^2).$$

[0012]

A modification example of Figure 1 is shown in Figure 7. Here, movable member 22 comprising fixed member 1 having comb-like fixed electrode 11C and movable electrodes 22A and 22B which engage said [fixed electrode] to slide while keeping a small gap between the respective teeth is provided. Movable electrodes 22A and 22B are identical to those in Figure 1. They are insulated from each other via insulator 22C just as in said figure, and small protrusion parts 4A and 4B are provided on fixed member 1 so as to allow movable member 22 to slide with little friction. As such, movable member 22 makes contact only at said parts. In other words, the

parts containing protrusion parts 4A and 4B constitute first and second junctions 5A and 5B for applying voltages to 2 movable electrodes 22A and 22B; first junction 5A and first movable electrode 22A are connected to each other, and second junction 5B and second movable electrode 22B are connected to each other; and the 2 junctions are insulated from fixed electrode 11C via another insulator 22D. 6A and 6B are switches. When they are in the positions illustrated, a positive voltage is applied to second junction 5B and second movable electrode 22B, and a negative voltage is applied to first junction 5A and first movable electrode 22A and to fixed electrode 11C; and said relationship is reversed when they are in the positions indicated by the dotted lines. From the description given above, the present application example can be said to be equivalent to the one shown in Figure 1 when it is rotated by 90°.

[0013]

With said configuration, with the voltages applied to the respective electrodes in the manner indicated by the solid lines, a displacement takes place in the direction indicated by the solid-line arrow due to the field generated between first and second movable electrodes 22A and 22B and fixed electrode 11C as explained in Figure 2. On the contrary, when a voltage is applied to the respective electrodes in the manner indicated by the dotted lines, voltages of first and second movable electrodes 22A and 22B are reversed, so displacement takes place in the direction indicated by the broken-line arrow. When so configured, an actuator capable of attaining a large displacement in an amount corresponding to the length of the fixed electrode can be realized. Here, the driving force can be improved by increasing the number of teeth or by providing a movable member in parallel at an appropriate distance. Furthermore, although it is not illustrated, needless to say, one of the 2 movable electrodes and the insulator may be replaced with a dielectric in this case also.

[0014]

An example piston-type actuator is shown in Figure 8. Here, disk-like first and second movable electrodes 23A and 23B are layered via intervening insulator 23C to configure movable member 23 and placed in cylindrical fixed electrode 11D having a diameter slightly larger than the outer diameter of said movable member. Conductive guide members 3C and 3D are attached perpendicular to the respective planes of first and second movable electrodes 23A and 23B and supported by bearings 7A and 7B. Then, as illustrated, for example, when first movable electrode 23A and fixed electrode 11D are short-circuited, and a voltage is applied between second movable electrode 23B and fixed electrode 11D, movable member 23 is displaced in the direction indicated by the arrow and generates an outward force via guide members 3C and 3D. Because the displacement can be controlled in accordance with the length of cylindrical fixed electrode 11D, a large stroke can be attained. An example in which one of the 2 movable electrodes and the insulator are replaced with a dielectric is shown in Figure 9. Since the principle is the same as that explained in Figure 6, explanation of its details will be omitted. 23D represents the dielectric.

[0015]

An example electrostatic motor is shown in Figure 10, and its cross section indicated by A-A'-B is shown in Figure 11. Here, a comb-like fixed electrode is used for stator 11E, rotor 24 having mutually insulated 4 movable electrodes 24A, 24B, 24C, and 24D is provided so as to engage said [stator], and 2 rotary electrodes 8A and 8B are provided at its shaft part to make rotation easy. Furthermore, first and third movable electrodes (24A and 24C) are connected to first rotary electrode 8A, and second and fourth movable electrodes (24B and 24D) are connected to second rotary electrode 8B; and they are fixed by pressure using 2 brushes 9A (one is omitted)

and 9B so as to allow rotation of rotary electrodes 8A and 8B around stator 11E. Then, when second brush 9B is short-circuited with stator 11E, and a voltage is applied between first brush 9A and stator 11E, voltages of respective movable electrodes 24A, 24B, 24C, and 24D are arranged in the manner shown in Figure 11. As a result, the first and third electrodes and the stator are attracted to each other to cause rotation in the direction indicated by the arrow.

[0016]

In the example in Figure 10, too, when the second and fourth movable electrodes are replaced with a dielectric, such as a resin film, and driven in a liquid, such as flon or alcohol, instead of in the air, a large torque can be attained. At this time, there is no need to short-circuit second brush 9B with stator 11E. Because the electrostatic attraction created between the front and the back planes of the first and third movable electrodes and the stator are both reduced on one side by the dielectric, an unbalance of force is created to cause a rotation. As described above, because the electrostatic force acted upon the comb-like movable electrode is utilized constantly during the rotation, a great advantage occurs in that a large torque can be attained.

[0017]

An example electrostatic motor is shown in Figure 12. Here, first and second movable electrodes 25A and 25B are created by cutting disk-like rotor 25 at some places, and the configuration is such that a voltage can be applied from above and below shaft 10. At this time, first and second movable electrodes 25A and 25B are insulated from each other via an insulator. Then, when rotor 25 is sandwiched by conductive stators 11F and 11G while keeping an appropriate gap from them and fixed in such a manner that a voltage can be supplied to second

movable electrode 25B from shaft holding part 12 of stator 11F, and when the voltage is applied according to the relationship illustrated, it rotates in the direction indicated by the arrow.

[0018]

Effect of the invention

With the present invention, when a pair of comb-like movable electrodes (the configuration may be realized using an electrode and a dielectric in place of the pair of movable electrodes) insulated respectively and a comb-like fixed electrode are to engaged with each other, and voltage is applied to one of the movable electrodes and between the fixed electrode and the remaining electrode, a large driving force be attained, and displacement cant can be increased as a result.

<u>Brief description of the figures</u>

Figure 1 is a slanted view showing an application example of the present invention.

Figure 2 is a diagram for explaining a principle of the present invention.

Figure 3 is an outlined diagram for explaining the fabrication method in Figure 1.

Figure 4 is a slanted view showing an application example in which the movable member is layered.

Figure 5 is an outlined diagram for explaining the fabrication method in Figure 4.

Figure 6 is a diagram for explaining another principle of the present invention.

Figure 7 is a slanted view showing a modification example of Figure 1.

Figure 8 is an outline diagram showing an application example of a piston-type actuator.

Figure 9 is an outline diagram showing another application example of a piston-type actuator.

Figure 10 is a slanted view showing an example electrostatic motor.

Figure 11 is a cross section of Figure 10 along A-A'-B.

Figure 12 is a slanted view showing another example of the electrostatic motor.

Figure 13 is an outlined diagram showing a conventional example.

Figure 14 is an outlined diagram showing another conventional example.

Symbols

1	Fixed member
2	Movable member
10	Shaft
11	Fixed electrode
12	Shaft holding part
21	Movable electrode
22	Movable member
23	Movable member
24	Rotor
25	Rotor
3A	Guide member
3B	Guide member
4A	Protrusion part
4B	Protrusion part
5A	First junction
5B	Second junction
6A	Switch
6B	Switch
7A	Bearing
7B	Bearing
8A	First rotary electrode
8B	Second rotary electrode
9A	Brush
9B	Brush
11A	Fixed electrode
11B	Fixed electrode
11C	Fixed electrode
11D	Fixed electrode
11E	Stator
11F	Stator
11G	Stator
21A	Movable electrode
22A	First movable electrode

22B	Second movable electrode
22C	Insulator
23A	First movable electrode
23B	Second movable electrode
23C	Insulator
23D	Dielectric
24A	First movable electrode
24B	Second movable electrode
24C	Third movable electrode
24D	Fourth movable electrode
25A	First movable electrode
25B	Second movable electrode

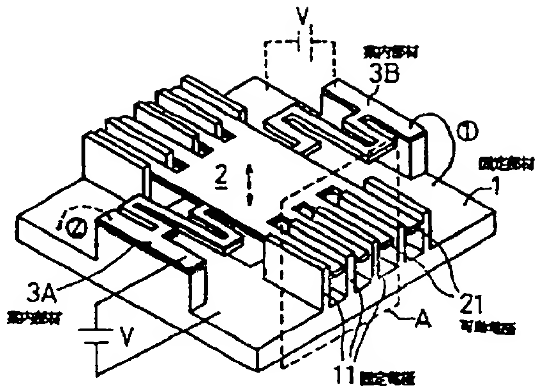

Figure 1

Key:		
	1	Fixed member
	3A, 3B	Guide member
	11	Fixed electrode
	21	Movable electrode

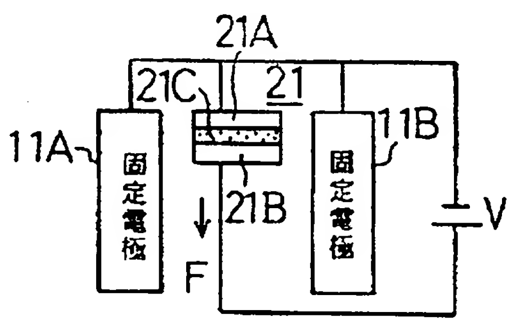

Figure 2

Key: 11A, 11B Fixed electrode

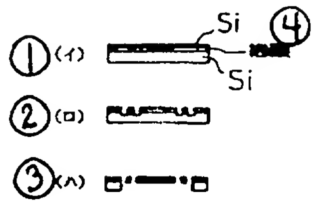

Figure 3

Key: 1 (A)
2 (B)
3 (C)
4 Insulating film

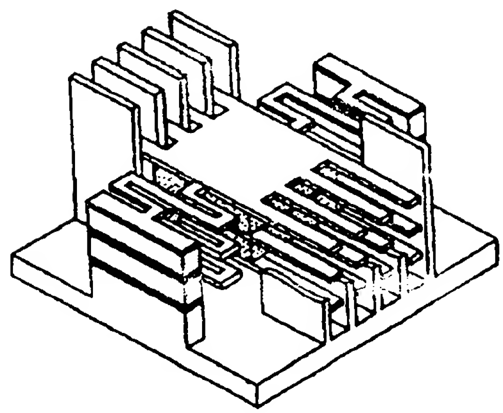

Figure 4

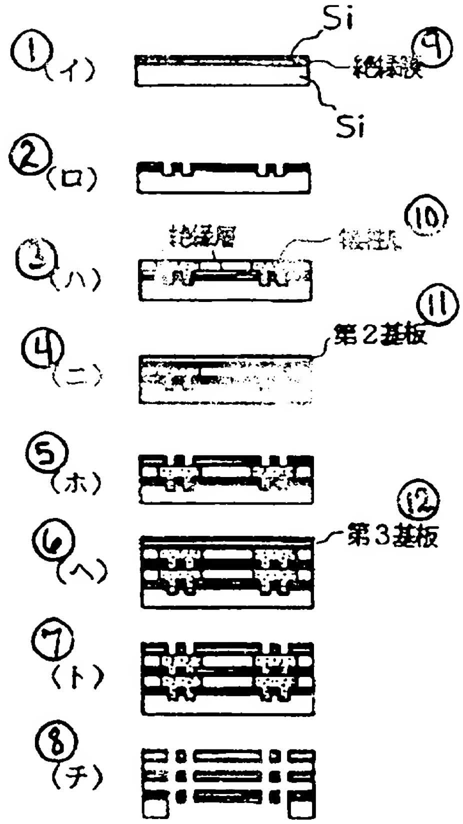

Figure 5

Key:	1	(A)
	2	(B)
	3	(C)
	4	(D)
	5	(E)
	6	(F)
	7	(G)
	8	(H)
	9	Insulating film
	10	Sacrificial layer
	11	Second substrate
	12	Third substrate

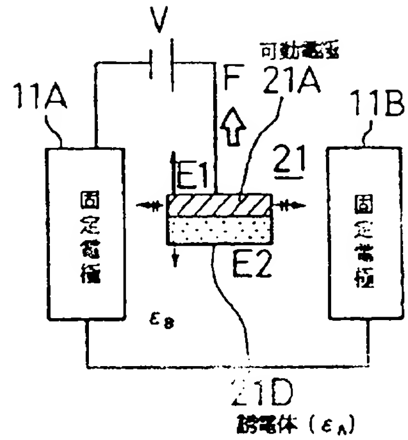

Figure 6

Key: 11A, 11B Fixed electrode
21A Movable electrode
21D Dielectric

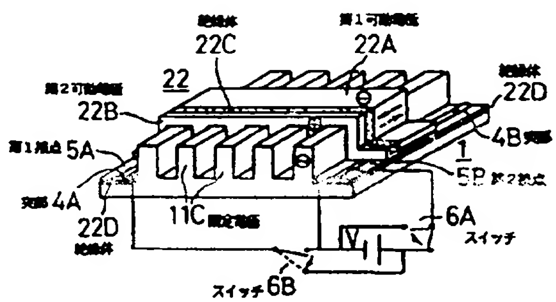

Figure 7

Key:

4A, 4B	Protrusion part
5A	First junction
5B	Second junction
6A, 6B	Switch
11C	Fixed electrode
22A	First movable electrode
22B	Second movable electrode
22C, 22D	Insulator

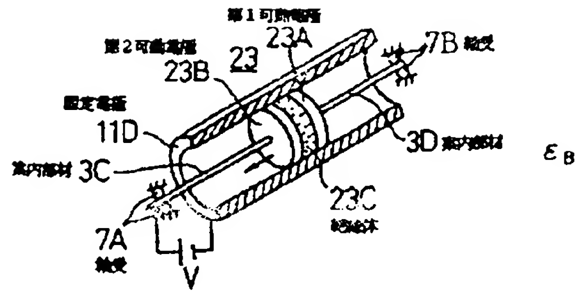

Figure 8

Key:

3C, 3D	Guide member
7A, 7B	Bearing
11D	Fixed electrode
23A	First movable electrode
23B	Second movable electrode
23C	Insulator

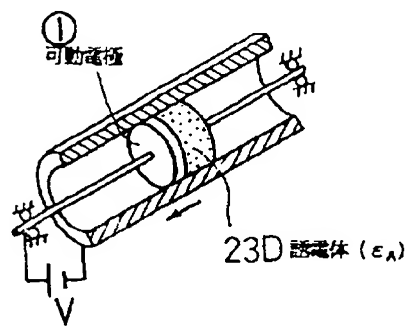

Figure 9

Key:

1	Movable electrode
23D	Dielectric

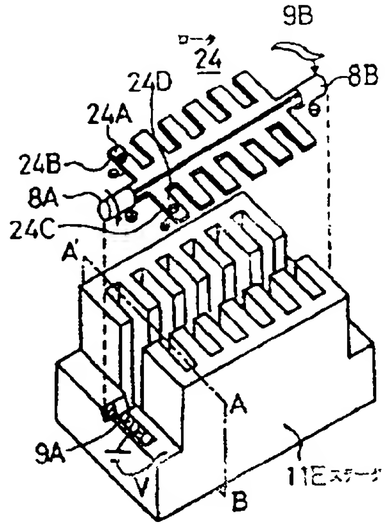

Figure 10

Key: 11E Stator

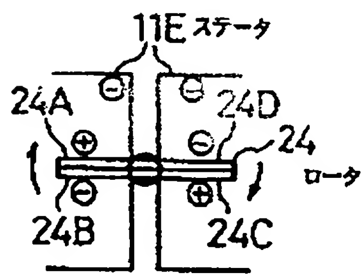

Figure 11

Key: 11E Stator

24 Rotor

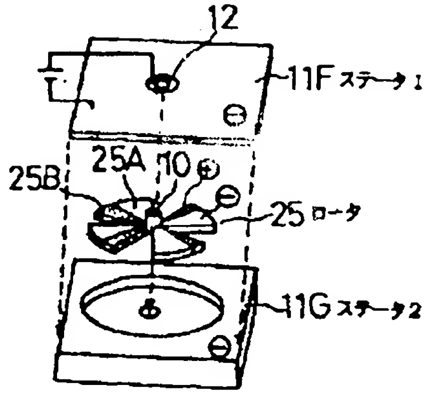

Figure 12

Key:	11F	Stator 1
	11G	Stator 2
	25	Rotor

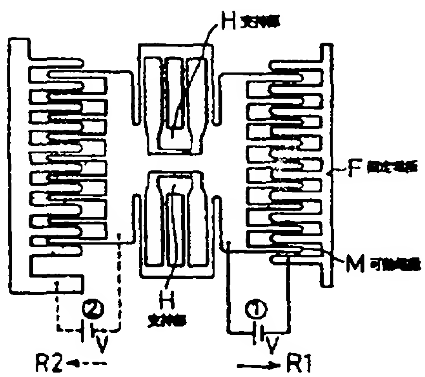

Figure 13

Key:	F	Fixed electrode
	H	Holding part
	M	Movable electrode

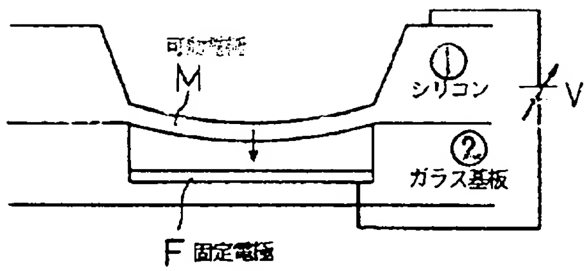

Figure 14

Key:	F	Fixed electrode
	M	Movable electrode
	1	Silicon
	2	Glass substrate